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TITLE: **Studying Upper-Limb Amputee Prosthesis Use to Inform Device Design**

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
The proposed project investigates the nature of upper limb prosthesis use in everyday tasks through in-home and lab-based studies on upper-limb amputees and matched unimpaired subjects.
During the second year we recruited amputee participants and completed several at-home portions of the study. A study of the resulting videos led to a new prosthetics-use taxonomy that is generalizable to various levels of amputation and terminal devices. The taxonomy was applied to classification of the recorded videos via custom tagging software with midi controller interface. The software creates Matlab-readable log files. Motion capture development of a body compensation experiment and kinematics based metric were also made.
In the next year recruitment of amputee and able bodied participants will continue in an effort to complete more studies and generate data for analysis.

15. SUBJECT TERMS
Upper Limb Prosthetics, Amputee, Assistive Technology, Motion Capture

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1. INTRODUCTION

The proposed project centers on investigating the nature of upper limb prosthesis use in everyday tasks through both an in-home and lab-based study on upper-limb amputees and age and gender-matched normal subjects. For the in-home study we will use an unobtrusive head-mounted camera to record and then later observe prosthesis/hand use during domestic tasks. In the lab study we will use a motion capture studio and video cameras to record accurate and detailed upper body motion during a series of standardized tasks. These tasks are clinically validated measures of hand / arm function functional evaluation. By recording participant performance and examining prosthesis/hand use, we expect to identify shortcomings in current terminal devices and implementations that will inform improvements to existing designs and inspire new classes of devices in the future.

2. KEYWORDS

Upper Limb Prosthetics, Amputee, Assistive Technology, Motion Capture

3. ACCOMPLISHMENTS

This reporting period covers the second year of the project. This portion of the project has involved subject recruitment efforts and initial data capture and data analysis, using custom software tools.

What were the major goals of the project?

The major goals of this project were observing the upper limb manipulation techniques used by numerous upper limb prosthesis wearers and ‘healthy’ individuals (i.e. those with intact upper limbs) when achieving a variety of tasks in unstructured (in their own home) and structured (in the lab) environments. Comparing data from these two demographics over the different tasks and environment we aim to determine differences in manipulation techniques between prosthesis wearers and the healthy ‘baseline’. In particular we wish to identify the shortcomings of particular prosthetic devices or setups while looking for methods employed by prosthesis users to overcome these limitations. These

Originally the study proposed the use only of head-mounted cameras for observation. This was extended to include a motion capture system capable of accurately recording upper body motion to provide much richer movement data. The motion capture setup will be used only in the laboratory setup, due to the complexity of the measurement equipment and relatively limited capture volume.

What was accomplished under these goals?

In the **first year** we prepared measurement equipment and the necessary protocols to enter participants into our study. In particular the following achievements were made:

1. Experimental protocols were finalized
2. The protocol was approved by IRBs for all institutions and the DoD. Necessary human subjects training was also completed for relevant members of the study team.
3. The head-mounted camera setup has been established (a modified GoPro Hero 3 with external pocket sized battery – giving 6 hours of recording).
4. Software to aid analysis of the head-mounted camera data was prototyped
5. A Vicon optical motion capture system was selected (after reviewing several options), purchased and installed in the laboratory space of Yale University
6. Extensive familiarization with the Vicon system was completed. This began with on-site training from a Vicon representative but since then has led to the following:
    a. Optimized camera placement (13 cameras in a 5x5m space) for bi-manual upper body capture when standing or seated. This also involved installing mounting rails in the laboratory
    b. Optimized marker placement for robustness to marker occlusions (when motion capture markers are hidden from view in particular body poses). This includes flexible, wearable marker clusters and custom software methods to reconstruct occluded markers.
    c. Custom data processing scripts to extend the functionality of Vicon software to export skeletal angles. These scripts have been written to match the guidelines of the international society of biomechanics (ISB)
7. Collection and setup of materials for the laboratory space. This includes a variable height desk (to simulate a kitchen counter or work desk) and various household items.

The setup of equipment took longer than initially suggested in the original proposal. This was due to the inclusion of the motion capture system. This system required development of specific skills and significant trial and error regarding camera placement, focusing and marker sets.

In the **second year** of the project the following further development were made:

1. A pilot study was completed of the at-home study with a healthy non-amputee volunteer. This highlighted problems with reliability of the GoPro remote control and particular brands of memory card.
2. Amputee participant recruitment began, with various advertisements placed in amputee online forums and social media sites.
3. Three amputee participants were recruited within Connecticut and New York. Two were congenital transradial amputees (one male, one female, both body powered users) and

one was a non-congenital shoulder disarticulation amputee (who uses a myoelectric prosthesis)

4. Custom Video Analysis software was completed, allowing quick and robust video tagging by use of a midi controller. Exported log files may be read by Matlab or Excel.
5. An initial 'prosthesis use taxonomy' was created, based on observation of the video, to allow structured recording and categorization of manipulation events observed in the recorded videos.
6. The recruited amputees all took part in the at-home study.
    a. Several hours of video data were generated for each participant
    b. A number of participant videos were de-identified via blurring of portions of the video
    c. Initial video tagging was completed by use of the custom software. A summer intern was hired and trained for this task. He will continue to work with us in his spare time for the remainder of the project.
    d. Initial trends were observed in video tagging log files, via Matlab analysis.
7. Further preparations were made for Motion Capture analysis, including a full pilot study with members of the lab
    a. An additional body compensation analysis was planned and piloted on members of the laboratory

What opportunities for training and professional development has the project provided?

The project provided the opportunity for familiarization with literature on prosthetics, motion capture and functional outcome measures. As part of this familiarization, the conference MEC (Myoelectric Controls Symposium, New Brunswick Canada) was attended by members of the project during the first year.

Technical training was completed by Dr Adam Spiers on the Vicon motion capture system. Training was also completed by Dr. Spiers on protocols and policies regarding human experiments. Dr. Spiers has subsequently trained two grad students in how to use the motion capture system and written a guide for use in the lab.

As a result of the at-home studies, Dr. Spiers has become familiar with running studies in non-laboratory scenarios.

An undergraduate summer intern was employed for video tagging and video de-identification (selective scene blurring). This provided the individual with an understanding of the functioning of a research lab, while also developing their video editing and processing skills.

How were the results disseminated to communities of interest?

Internal dissemination of initial findings have been presented to our lab. We have not discussed findings outside of the lab yet.

What do you plan to do during the next reporting period to accomplish the goals?

In the next period we plan the following

1. To recruit more amputee participants and complete at-home studies with them.
2. To recruit gender, age and height matched non-amputee participants and complete home studies with them
3. To continue tagging of the at-home video data using the custom video tagging software
4. To complete in-lab motion capture studies with all recruited participants
5. To analyze the vicon motion capture data and look for trends in the data
6. To disseminate the results via publications

IMPACT

What was the impact on the development of the principal discipline(s) of the project?

Describe how findings, results, techniques that were developed or extended, or other products from the project made an impact or are likely to make an impact on the base of knowledge, theory, and research in the principal disciplinary field(s) of the project. Summarize using language that an intelligent lay audience can understand (Scientific American style).

The manipulation taxonomy developed for this work fills a gap in prosthetics terminology that we assume will be used by other researchers in the future. Such manipulation taxonomies (e.g. the Feix taxonomy) are widely used in healthy human and robotic hand analysis, yet no such tool exists for prosthetics use. Though Belter et al created a 'split hook' taxonomy, this was not applicable to other terminal devices, such as multi-finger hands. We have designed the taxonomy to be generic and applicable to all upper limb prosthetic systems and levels of amputation.

Similarly, we believe the body compensation measure under development for this project will also provide a tool that may be useful for motion analysis in research, and possibly clinical setting. Despite body compensation being a known, unwanted factor of motion impairment, there is no universal method of quantifying the level of compensation for particular motions. This is addressed by our kinematics based algorithm, which may be easily added to a motion capture analysis.

What was the impact on other disciplines?

Nothing to report

What was the impact on technology transfer?

Nothing to report

What was the impact on society beyond science and technology?

Nothing to report

5. CHANGES/PROBLEMS:

Changes in approach and reasons for change

Addition of motion capture to the in-lab portion of the proposed study.

In the guidance for the home study, we specified that participants are not permitted to spend more than 30 minutes on sedentary activities such as watching television or reading a book. As this may have been abnormal for some participants, we had statements from some volunteers that they ‘ran out of things to do’. A guideline document of suggested activities was therefore provided, including such tasks as

Actual or anticipated problems or delays and actions or plans to resolve them

Year 1 - Training, setup and familiarization of with the motion capture system added delays to the project compared to the original forecast. However we believe the quality and impact of the resulting data will be much higher as a result of this new measurement tool and the time taken to learn how to use it.

Year 2 – Difficulties in participant recruitment delayed the start of the at-home study and has slowed down project progress. Typical channels of subject recruitment (online advertisements) did not generate any participants. Instead personal connections through team members and/or their colleagues led to subject recruitment in all cases.

Changes that had a significant impact on expenditures

Nothing to report

Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents

Nothing to report

6. PRODUCTS:

Publications, conference papers, and presentations

Nothing to report

Website(s) or other Internet site(s)

Nothing to report

Technologies or techniques

Motion capture marker sets and processing techniques associated have been developed. These will accompany future publications as appendices.

The Midi controller based video tagging software developed for this project is robust and easily scalable. We are considering open-sourcing the code afterwards for use by other researchers.

The prosthetics use taxonomy is a manipulation classification technique that will be applicable to general analysis of upper limb prosthesis use.

The body compensation algorithm will be published with accompanying data, following completion of the in-lab study.

Inventions, patent applications, and/or licenses

Nothing to report

Other Products

Nothing to report

7. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

What individuals have worked on the project?

Name:	Aaron Dollar
Project Role:	PI
Researcher Identifier (e.g. ORCID ID):	
Nearest person month worked:	1
Contribution to Project:	**Expert on human hand functional use and robot / prosthetic hand development. Contributed to Protocol development, measurement equipment selection and setup.**
Funding Support:	This award.

Name:	Linda Resnik
Project Role:	Co-PI
Researcher Identifier (e.g. ORCID ID):	
Nearest person month worked:	1.2
Contribution to Project:	**Expert on upper limb prosthetics and measures of upper limb functionality and rehabilitation outcomes. Contributed to protocol development.**
Funding Support:	This award

Name:	Adam Spiers
Project Role:	Postdoctoral Associate

Researcher Identifier (e.g. ORCID ID):	
Nearest person month worked:	2
Contribution to Project:	**Postdoc researcher responsible for running at-home and in-lab studies. Contributed to protocol development, IRB submission (Yale only), equipment selection, setup, customization and familiarization.**
Funding Support:	This award.

Name:	Kate Barnabe
Project Role:	Administrative Lead
Researcher Identifier (e.g. ORCID ID):	
Nearest person month worked:	1.2
Contribution to Project:	**Protocol development. IRB submissions (all institutions and DOD). Project administration.**
Funding Support:	This award

Name:	Paedyn Gomes
Project Role:	Undergraduate Intern
Researcher Identifier (e.g. ORCID ID):	
Nearest person month worked:	2
Contribution to Project:	**Video de-identification Video Tagging**
Funding Support:	This award

Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?

Nothing to report

What other organizations were involved as partners?

Nothing to report

8. SPECIAL REPORTING REQUIREMENTS

A Quad Chart accompanies this report

9. APPENDICIES

None

Studying Upper-Limb Amputee Prosthesis Use to Inform Device Design

Log# 13116005, Award# W81XWH1410277

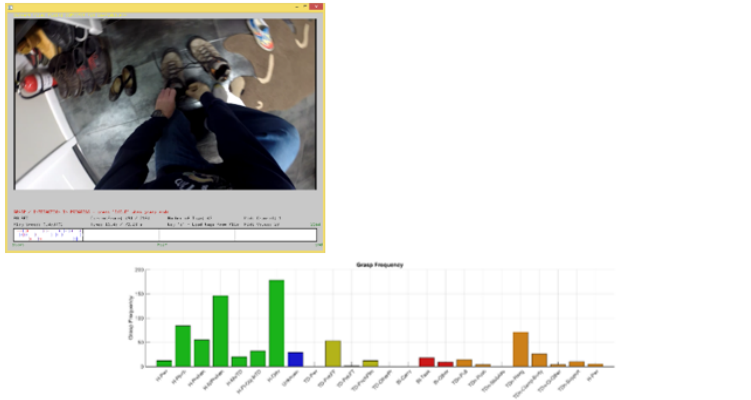
PI: Aaron M. Dollar **Org:** Yale University **Award Amount:** $476,646

Study/Product Aim(s)

- Investigate prosthesis use during daily living by upper-limb amputees
- Develop task-related prosthesis usage/non-usage statistics
- Examine compensatory motions/actions
- Identify areas for device improvement and opportunities for assistive technologies

Approach

The upper-limb usage of amputee and age/gender-matched unimpaired subjects will be examined in both their home environments and a fixed laboratory environment doing a pre-described set of activities of daily living (ADLs). Their actions/movements will be recorded with head-mounted cameras (home) and motion-tracking equipment (lab).



Top-Left – Video footage from an amputee at-home study, being played back in our custom software. **Top-Right** - Tags applied to the video based on a custom taxonomy. **Bottom** – Distribution of manipulation events for one amputee participant.

Timeline and Cost

Activities | Milestone (m)	CY 14 Q	15 1 2 3 4	5 6 7 8	9 10 11 12
Protocol Develop | IRB Approvals		m		
Study Equipment | Fab complete		m		
Recruit Subjects | Enrollment complete			m	
Home-based video study | Completion			m	
Lab-based study | Completion			m	
Data analysis | Final Publication				m
Estimated Budget ($K)	**$25.6**	**$247**	**$95.4**	**$108.6**

Updated: (3/28/16)

Goals/Milestones

- ✓ Protocol Development and IRB submissions (months 1-12)
- ✓ Fabricate and Test study equipment (months 1-12)
- ○ study of ADL tasks (months 12-24)
- ○ Lab-based video Subject Recruitment (months 12-24)
- ○ Home-based video study of ADL tasks (months 12-24)
- ❑ Prepare and Analyze task performance data (months 15-36)

Comments/Challenges/Issues/Concerns

- Award began 09/08/14
- Rebudgeted to allow purchase of motion-tracking equipment
- In-home study is in progress
- Amputee recruitment proving more difficult than anticipated

Budget Expenditure to Date

Projected Expenditure: $317,000

Actual Expenditure: $321,100